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RESEARCH ARTICLE

The effects of autistic traits and academic degree on visuospatial abilities

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Abstract

In the present study, we were interested to investigate how autistic traits (including systemizing and empathy) and academic degree influence individuals' visuospatial abilities. To this end, 352 university students completed the Autism Spectrum Quotient (AQ), the Empathy Quotient, the Systemizing Quotient (SQ) and visuospatial tests measuring figure disembedding and mental rotation of two-dimensional figures. Engineering-design students (architecture and engineering) were the most accurate in disembedding and mentally rotating figures, followed by students of physical sciences (computer science, chemistry, physics, etc.) and fact-based humanities (languages, classics, law); biological (psychology and neuroscience, etc.) and systems-based social scientists (economics and commerce) were the least accurate. Engineering-design students also showed higher SQ scores with respect to the other four academic degree subjects, with students of biological sciences showing lower SQ scores. Importantly, results from a path analysis revealed that SQ (but not AQ) exerted an indirect effect on figure disembedding and mental rotations through the influence of the academic degree. Thus, the present findings reveal shady differences in systemizing degree and visuospatial performance within systemizing-based degree subjects. Implications for education are discussed.

Keywords Mental rotation · Disembedding figures · Systemizing Quotient · Empathy Quotient · Science, technology, engineering and mathematics (STEM)

Introduction

In recent years, a growing number of studies have been focusing on behavioural performance of neurotypical individuals with varying degrees of autistic traits. A continuum of autistic traits exists across the general population, with clinical autism representing the extreme end of a quantitative distribution (Baron-Cohen et al. 2001; Constantino and Todd 2003; Robinson et al. 2011). Three main questionnaires have been developed to measure traits relevant to autism within the general population (Baron-Cohen et al. 2001, 2003; Baron-Cohen and Wheelwright 2004). The Autism Spectrum Quotient (AQ, Baron-Cohen et al. 2001) quantifies autistic traits (social skill, attention switching, attention to detail, communication, imagination). The Systemizing Quotient (SQ, Baron-Cohen et al. 2003) assesses systemizing, defined as the preference for analysing, understanding and building up systems, a strength of individuals with Autism Spectrum Conditions (ASC). The Empathy Quotient (EQ, Baron-Cohen and Wheelwright 2004) measures cognitive empathy, as judging, interpreting or anticipating another's behaviour, that is impaired in ASC (Baron-Cohen 2002) compared to a relatively spared emotional empathy (e.g. Dziobek et al. 2008).

By using these measures, it is possible to test relationships between autistic traits and specific cognitive skills (Walter et al. 2009). For instance, several studies showed

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that neurotypical people with high levels of autistic traits outperform people with low levels of autistic traits on visuospatial tasks as embedded figures (Grinter et al. 2009a, b), block design (Grinter et al. 2009b; Stewart et al. 2009), Navon figures (Navon 1977; English et al. 2017; Sutherland and Crewther 2010) and mental rotations (Stevenson and Nonack 2018).

These differences seem similar to differences between females and males on the same measures. Typical females, on average, are characterized by a bias towards higher empathizing, whereas typical males, on average, are characterized by a bias towards higher systemizing (Baron-Cohen and Wheelwright 2004; Baron-Cohen et al. 2003). Accordingly, men tend to outperform women on visuospatial tasks as embedded figures and mental rotations (Auyeung et al. 2012; Baron-Cohen 2002; Brosnan et al. 2010). These findings would support the extreme male brain theory of autism which sees autism as the expression of an extreme masculinization of the typical male cognitive profile (Baron-Cohen 2002; Baron-Cohen et al. 2015; Greenberg et al. 2018), and associated with elevated foetal exposure to testosterone during pregnancy (Baron-Cohen et al. 2015). However, contrasting data on whether sex differences in visuospatial performance actually overlap with differences between ASC and neurotypical individuals suggest to further investigate the relationship between foetal testosterone and visuospatial abilities (Auyeung et al. 2012; Brosnan et al. 2010; Falter et al. 2008; Muth et al. 2014; Zapf et al. 2015).

Individual differences in self-reported systemizing and empathizing can predict why some people choose academic majors focused on rule-based phenomena, such as science, technology, engineering and mathematics (STEM), whereas other persons choose majors mainly requiring people understanding, such as social sciences and humanities (Kidron et al. 2018; Manson and Winterbottom 2012; Morsanyi et al. 2012; Wheelwright et al. 2006). Interestingly, some studies suggest that not only scores on questionnaires of systemizing and empathizing but also performance on cognitive tasks can predict entry into different academic majors, since physical scientists outperform social scientists on visuospatial tasks as embedded figures and mental rotation (Billington et al. 2007; Carroll and Yung 2006; Groen et al. 2018). This is consistent with the data showing that better visuospatial abilities measured in adolescence are predictive of later achievements and occupations in STEM (Wai et al. 2009).

The extreme male brain theory can offer a biological explanation for sex differences in STEM, since the stronger tendency of females to empathize together with less visuospatial abilities could explain their preference for humanities, whereas the stronger tendency of males to systemize together with stronger visuospatial abilities could explain their preference for STEM (Baron-Cohen 2002; Baron-Cohen et al. 2015; Greenberg et al. 2018; Kidron et al. 2018; Morsanyi et al. 2012). However, a different line of research demonstrated that practising with spatial-related activities can reduce, or even cancel, sex differences in visuospatial performance and that individual differences on visuospatial tasks are also related to environmental factors, such as experience (Bergner and Neubauer 2011; Goldstein and Chance 1965; Kass et al. 1998; Meneghetti et al. 2015; Rodán et al. 2016; Uttal et al. 2013). Interestingly, for instance, in a relevant meta-analysis, Uttal et al. (2013) showed that training with visuospatial tasks can shape differences in visuospatial performance related not only to sex but also to factors such as individual variability in the initial level of performance.

Altogether, data reviewed above suggest that a complex interplay exists between autistic traits, including systemizing and empathizing, visuospatial abilities and academic degree (STEM vs. social sciences), regardless of sex. In the present study, we aimed at shedding lights on this complex relationship by investigating how autistic traits and academic degree predict individuals' visuospatial abilities. To this scope, we recruited a large sample of university students from different academic majors. Importantly, moreover, we developed a fine-grained, five-group classification of the academic subjects considering possible similarities between majors usually included in different academic categories.

Classical studies (Baron-Cohen et al. 2001; Wheelwright et al. 2006) categorized the academic degree subjects into four groups: physical sciences, biological sciences, social sciences and humanities. Such a classification revealed that physical scientists outperform both social scientists and humanities students on visuospatial tasks (Billington et al. 2007; Groen et al. 2018) and also show stronger systemizing tendencies (Baron-Cohen et al. 2001; Billington et al. 2007; Focquaert et al. 2007; Groen et al. 2018; Kidron et al. 2018; Wheelwright et al. 2006). However, as suggested by Wheelwright et al. (2006), this classification tends to include in the same academic category majors actually involving different degrees of systemizing.

One relevant example is humanities, which includes several different majors such as languages, drama, education, law and architecture. Another example comes from university departments in several countries keeping together civil, building, environmental engineering and architecture. All these disciplines essentially deal with the process of creating and designing physical structures. Moreover, people in these disciplines are engaged in processing and manipulating visuospatial information. On this basis, we decided to revise the classical academic degree subject classification, specifically redefining the categories of physical sciences and humanities. All branches of engineering dealing with design were included in a new group, labelled engineering-design, which also included architecture. The remaining branches of engineering dealing with computer science, chemistry and biomedicine remained in physical sciences. Fact-based humanities included majors that focus mainly on facts (classics [fact-based history and the syntax/vocabulary of ancient languages], languages [the facts of syntax and vocabulary] and law [the facts of specific pieces of legislation]). The same was true for systems-based social sciences, mainly comprising economics (Wheelwright et al. 2006). Thus, our classification differentiated academic degree subjects into: (i) physical sciences; (ii) engineering-design; (iii) fact-based humanities; (iv) biological sciences and (v) systems-based social sciences (see Methods for the precise composition of each group). We excluded the non-systems-based social sciences and the non-fact-based humanities because our interest was to look at subtle differences within systemizing-based degree subjects, rather than look at extreme differences between systemizing- and non-systemizing-based degree subjects.

Here, we first compared the profile of autistic traits and visuospatial performance of the five groups. Then, a path analysis was conducted to test the hypothesis that autistic traits, including systemizing and empathizing, influenced individuals' visuospatial abilities through the effect of the academic degree subject. As measures of visuospatial abilities, we used two embedded figure tests and a two-dimensional mental rotations task. We expected that our five-group classification of the academic subjects would allow to reveal shady differences within systemizing-based degree subjects not found in the previous literature that instead focused on overt differences between systemizing- and non-systemizing-based subjects. Moreover, by modelling relations between traits, academic degree subject and visuospatial abilities, we expected to find that systemizing exerted an indirect effect on visuospatial performance via the specific influence of the type of academic degree.

Methods

Participants

Participants were 352 university students (166 females and 186 males) recruited from different universities in the Campania region, Southern Italy. All participants spoke Italian as their native language, had a mean age of 23.35 years (SD = 2.09) and were engaged in the study of their topic for at least 3 years ($M = 4.11$; SD = 1.03; range = 3–6 years). To be included in the study, each participant had to meet the following inclusion and exclusion criteria: (i) lack of any current neurological or psychiatric conditions, (ii) lack of any history of psychiatric difficulties (e.g. depression, bipolar illness, psychosis or anorexia), (iii) Italian as the first language.

As reported above, a five-group classification was adopted. (Demographic features of the groups are reported in Table 1.)

Group 1: Physical sciences (computer science, computer engineering, chemistry, chemical engineering, mathematics, physics and physical natural sciences, biomedical and electrical engineering.

Group 2: Engineering-design (civil, building, environmental and marine engineering and architecture).

Group 3: Fact-based humanities (law, classics, languages and philosophy).

Group 4: Biological sciences (biology, biological sciences, medicine and psychology).

Group 5: Systems-based social sciences (economics, commerce and political science).

The research was conducted after participants provided written informed consent and in accordance with the ethical standards of the Helsinki Declaration.

Table 1 Demographics of students separately for the five academic degree subjects

	Physical sciences[a] ($N = 95$)	Engineering-design[b] ($N = 57$)	Fact-based humanities[c] ($N = 59$)	Biological sciences[d] ($N = 93$)	Systems-based social sciences[e] ($N = 48$)
Mean age	23.1 ± 2.1	22.8 ± 1.4	23.15 ± 2.1	24.13 ± 2.3	23.25 ± 1.8
Years of university enrolment	4.2 ± .9	4.3 ± .9	4.3 ± 1.2	3.9 ± 1.1	3.6 ± .8
Number of males	58	29	29	47	24

[a] Physical sciences: computer science and computer engineering (45% of participants); chemistry and chemical engineering (25%); mathematics, physics and physical natural sciences (21%); and biomedical and electrical engineering (9%)

[b] Engineering-design: architecture (63%); and civil, building, environmental and marine engineering (37%)

[c] Fact-based humanities: languages and classics (55%); law (40%); and philosophy (5%)

[d] Biological sciences: psychology and neuroscience (50%); medicine (25%); and biology and biological sciences (25%)

[e] Systems-based social sciences: economics and commerce (75%); and political science (25%)

Measures

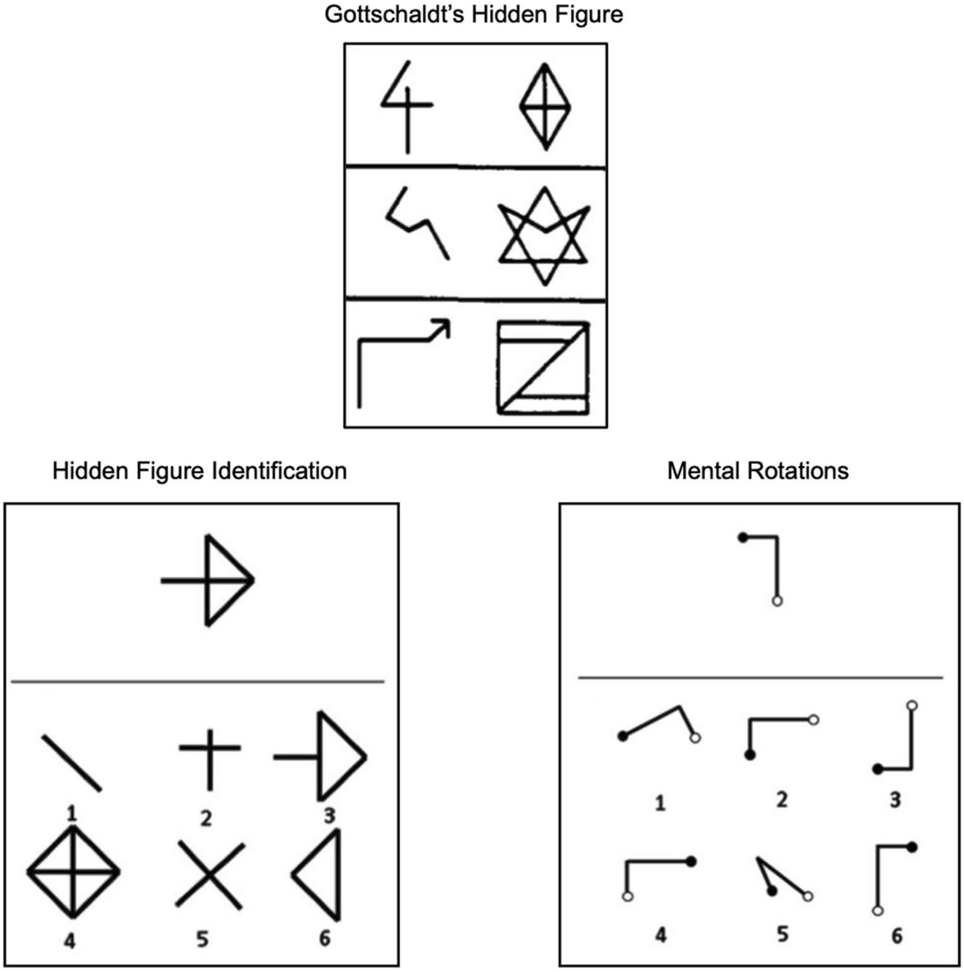
Visuospatial tasks

Three paper-and-pencil visuospatial tests (Fig. 1) were administered in a randomized order across participants: two disembedding figures tasks, the Gottschaldt's Hidden Figure Test (Gottschaldt 1926) and the Hidden Figure Identification (La Femina et al. 2009), and one task assessing two-dimensional mental rotations (La Femina et al. 2009).

In the *Gottschaldt's Hidden Figure Test* (GHFT; Gottschaldt 1926; Capitani et al. 1988), participants are presented with a series of complex geometrical figures in which a simple shape is hidden. The task requires participants to identify, for each item, the simple figure embedded within the corresponding complex pattern by using a pencil to trace the lines of the simple shape. Four tables compose the test material. In the first three tables containing nine items each, participants need to search for the simple figure (on the left side) within the complex figure (on the right side) and highlight it in. In the last table, instead, the simple figure is located at the centre of the sheet; the subjects have to identify it within seven different complex figures placed above and below the simple shape. Each correct choice is scored 1 (score range: 0-34). The total time needed to solve the 34 items is recorded.

In the *Hidden Figure Identification* (HF; La Femina et al. 2009; Trojano et al. 2015), participants are presented with a target stimulus and six abstract figures (i.e. the correct response and five distractors). The task requires participants to identify in the six-choice display the figure embedded in the target stimulus by verbally reporting the number corresponding to the selected option. To give the correct answer, participants have to mentally disassemble the target stimulus. There are 12 items of increasing complexity. Each correct choice is scored 1 (score range: 0–12). The total time needed to solve the 12 items is recorded.

In the *Mental Rotations* (MR; La Femina et al. 2009; Trojano et al. 2015), participants are presented with a stimulus target shaped as the capital letter L or S, with small white or black circles at the extremities. The six-choice display encloses the target-item stimulus, rotated on the horizontal plane by 45°, 90°, 135°, or 180°, together with five distractors that are mirror forms of the target stimulus at different


Gottschaldt's Hidden Figure

Hidden Figure Identification

Mental Rotations

Fig. 1 Examples of stimuli used for the visuospatial tests: three items are shown from the Gottschaldt's Hidden Figure Test (GHFT) and one item from both the Hidden Figure Identification (HF) and the Mental Rotations (MR) degrees of rotation. The task requires participants to indicate the item in the display that matches the target by verbally reporting the number corresponding to the selected option. There are 9 items of increasing complexity. Each correct choice is scored 1 (score range: 0–9). The total time needed to solve the 9 items is recorded.

Autistic traits

All participants completed the Italian version of the following three questionnaires: the Autism Spectrum Quotient (Baron-Cohen et al. 2001); the Empathy Quotient (Baron-Cohen and Wheelwright, 2004); and the Systemizing Quotient (Baron-Cohen et al. 2003).

The *Autism Spectrum Quotient* (AQ; Baron-Cohen et al. 2001; Ruta et al. 2012) quantifies the number of autistic traits an individual possesses across five domains (social skill, attention switching, attention to detail, communication and imagination) in both clinical and non-clinical samples. Participants were administered the full 50-item AQ (Baron-Cohen et al. 2001). Answering each question on the survey was mandatory, so there were no missing data for any participants who completed it. The results were scored according to Baron-Cohen et al.'s (2001) criteria, resulting in a total AQ score and in further five scores for the corresponding five subscales: social skill, attention switching, attention to detail, communication and imagination.

The *Empathy Quotient* (EQ; Baron-Cohen and Wheelwright 2004) measures empathy traits related to the recognition of others' emotions and moods, difficulties in which have been identified in ASC. Previous studies identified three subscales of EQ: cognitive empathy, emotional reactivity and social skills (Lawrence et al. 2004; Preti et al. 2011). Participants answered the 40-item short version of the EQ. The results were scored to obtain a total EQ score, which represents the subjects' level of empathy traits, i.e. the ability to understand others' emotions and moods. Moreover, three other scores were provided for the three factors: cognitive empathy, emotional reactivity and social skills.

The *Systemizing Quotient* (SQ; Baron-Cohen et al. 2003) evaluates across separate examples of systemizing to look at an individual's interest in a range of systems. The SQ comprises 60 questions, 40 assessing systemizing and 20 filler (control) items. Here, we used the Italian translation of the scale which is published on the website of the Cambridge Autism Research Centre (ARC; website https://www.autismresearchcentre.com/). The results provide a total SQ score indicating individual differences across the systemizing dimension, implying that a strong systemizer would be drawn to use their systemizing skills across the range of examples more often than a poor systemizer and would consequently score higher on the SQ.

Statistical analysis

First, we tested between-group differences in demographics by performing univariate ANOVAs on age, years of enrolment and on the number of males and females. Then, separate ANOVAs were conducted on the three visuospatial measures and on SQ, with degree subject (physical sciences vs. engineering-design vs. fact-based humanities vs. biological sciences vs. systems-based social sciences) and sex (females vs. males) as between-subject factors, with age of participants and years of university enrolment placed as covariates (see "*Demographics of the five groups*"). Two separate MANOVAs were conducted on the AQ and subscales and on EQ and subscales, with degree subject (physical sciences vs. engineering-design vs. fact-based humanities vs. biological sciences vs. systems-based social sciences) and sex (females vs. males) as between-subject factors, with age of participants and years of university enrolment placed as covariates. Post hoc *t* test comparisons were made to clarify significant main effects or interactions; Bonferroni correction for the multiple tests was applied when necessary. These analyses were performed using the Statistical Package for Social Sciences (SPSS Inc, version 15.0).

A path analysis was executed to test the reciprocal relation between autistic traits and the academic degree, and to test the direct and indirect effects of autistic traits on visuospatial performance. Path analysis is a multivariate technique for analysing the relations between different variables by hypothesizing the type of link and the direction of the relation between the considered variables (i.e. the model). In general, the basic model is defined by relying on theory, previous data and on the observed data. In the path analysis, it is possible to verify to what extent the hypothesized model is able to predict the observed data. Since this analysis can be considered an extension of the multiple regression, it cannot guarantee the validity of the causal implications in the data that instead remain a domain of theory.

In the present model, SQ total score and AQ attention to detail subscale were considered as exogenous variables, since previous findings demonstrated that these traits are related to academic degree and visuospatial performance (Baron-Cohen 2002; Billington et al. 2007; Carroll and Yung 2006; Groen et al. 2018; Stevenson et al. 2018); the academic degree subject and visuospatial performance (GHFT, HF and MR) were considered as endogenous variables. Moreover, academic degree subject was dummy coded into four variables with G1 (physical sciences) as the reference group: G1 versus G2 (engineering-design); G1 versus G3 (fact-based humanities); G1 versus G4 (biological sciences); and G1 versus G5 (systems-based social sciences). Physical sciences group was used as the reference because previous studies demonstrated that majors in this category require a high degree of systemizing (Baron-Cohen et al.

1998; Baron-Cohen 2002) and are also related to strong visuospatial abilities (Billington et al. 2007; Groen et al. 2018). Sex was not considered in the path analysis, since, as we will anticipate here (see Results section), sex never affected visuospatial performance, in line with previous data showing that sex differences are not related to, or are only marginally related to, visuospatial performance when autistic traits and academic degree are taken into account (Billington et al. 2007; Groen et al. 2018).

Following our hypothesis, in the path analysis we tested two models. In the first model (the basic model), all significant associations between autistic traits, academic subjects and visuospatial abilities, and between academic subjects and visuospatial abilities, were considered. Bivariate correlations were preliminarily computed in order to include in the basic model only the paths congruent with the theoretical model and that were significant (see Appendix A). Subsequently, all non-significant paths were removed, and the fit of the pruned model was tested. Therefore, in the pruned model, the hypothesized relations between each pair of considered variables were the same as in the basic model, and the only difference between the basic and the pruned models was that in the latter one the non-significant paths were fixed to zero, assuming that the two variables involved in the path were unrelated (independent). In this perspective, the pruned model is a simpler and more parsimonious model than the basic one, and since the pruned model includes fewer links between variables, it may be less able to explain the observed data than the basic model.

Path coefficients were estimated with Mplus 8.1 software by using the weighted least squares mean and variance estimator (WLSMV) and the theta parameterization. The significance of the direct and indirect effect was examined by computing the bias-corrected (BC) bootstrap 95% confidence intervals (CIs) based on 5000 iterations, which enables the detection of non-normality of the mediating effect (Shrout and Bolger 2002). Preliminarily, the fit of the basic model was tested, then the non-significant paths were pruned and the fit of the pruned model was tested and compared with the basic model. As fit indices (Geiser 2013), we used the maximum-likelihood (MLχ^2) goodness-of-fit test statistics in combination with the root-mean-square error of approximation index (RMSEA); the comparative fit index (CFI); and the ratio MLχ^2/df. The following values were considered as indicating good fitting models: $p > .05$ for MLχ^2 test; values $\leq .06$ for RMSEA; values $> .90$ for CFI; and values < 3 for ratio MLχ^2/df. Moreover, the difference in χ^2 statistics (MLχ^2_{diff}) tested with the DIFFTEST procedure was used to test relative fit of nested models (Geiser 2013).

Results

Demographics of the five groups

Students from the five degree subjects significantly differed in age (F(4348) = 6.11, $p = .0001$, $\eta_p^2 = .066$) and years of enrolment (F(4348) = 4.41, $p = .002$, $\eta_p^2 = .048$), whereas the number of males and females did not significantly differ between groups ($p > .05$); thus, as anticipated above, in the next statistical analyses, age and years of enrolment were used as covariates.

Effect of degree subject and sex on visuospatial tasks and autistic traits

The mean scores on GHFT, HF and MR separately for both the five degree subjects and sex are reported in Table 2.

The ANOVA on GHFT accuracy showed a significant main effect of degree subject (F(4341) = 8.19, $p = .0001$, $\eta_p^2 = .088$); Bonferroni corrected post hoc comparisons ($p = .0025$; .05/20) showed that students of engineering-design were significantly more accurate than physical scientists ($p = .001$), biological scientists ($p = .0001$) and systems-based social scientists ($p = .0001$), but not than students of fact-based humanities ($p > .0025$). Moreover, students of fact-based humanities were significantly more accurate than biological scientists ($p = .0001$), while no other comparisons were significant (all $p > .0025$). The main effect of sex and the degree by sex interaction were not significant (all $p > .05$).

The ANOVA on GHFT time score did not show significant main effects or interactions (all $p > .05$).

As regards HF accuracy, the ANOVA showed a significant main effect of degree subject (F(4341) = 6.53, $p = .0001$, $\eta_p^2 = .071$); Bonferroni-corrected post hoc comparisons ($p = .0025$) revealed that physical scientists, engineering-design and fact-based humanities students were significantly more accurate than biological scientists (all $p = .0001$) but not than systems-based social scientists ($p > .0025$); no other comparisons were significant (all $p > .0025$). The main effect of sex and the degree by sex interaction were not significant (all $p > .05$).

The ANOVA on HF time score did not show significant main effects or interactions (all $p > .05$).

The ANOVA on MR accuracy showed a significant main effect of degree subject (F(4341) = 4.44, $p = .002$, $\eta_p^2 = .050$); Bonferroni-corrected post hoc comparisons ($p = .0025$) showed that students of engineering-design were significantly more accurate than systems-based social scientists ($p = .0001$), while no other comparisons were significant (all $p > .0025$). The main effect of sex and the degree by sex interaction were not significant (all $p > .05$).

Table 2 Performance (accuracy and execution time) on the three visuospatial tests, separately for sex and degree subject

	Physical sciences		Engineering-design		Fact-based humanities		Biological sciences		Systems-based social sciences	
	M	F	M	F	M	F	M	F	M	F
GHFT										
Accuracy	7.8	7.9	8.3	8.2	8.1	8.1	7.5	7.7	7.6	7.7
	(1)	(.6)	(.3)	(5)	(.4)	(.6)	(.9)	(.9)	(.8)	(.9)
Time	68.7	66.5	59.1	57.9	68.2	65.8	70.8	66.8	63.5	61.1
	(26.1)	(24.7)	(17.6)	(18.8)	(34.7)	(28.1)	(23.5)	(23.2)	(19.7)	(16)
HF										
Accuracy	10.2	10.1	10.6	9.7	10.2	10.7	8.7	9.2	9.9	9.7
	(2.2)	(2.1)	(2)	(2.9)	(1.7)	(1.6)	(2.5)	(2.5)	(2.2)	(2.3)
Time	147.9	142.8	132.6	142.0	159.2	139.2	146.4	138.2	136.9	133.8
	(47.4)	(39)	(35.2)	(31.8)	(53.8)	(36.6)	(39.8)	(49.8)	(47.4)	(41.5)
MR										
Accuracy	6.6	6.6	7.1	7.4	7.3	6.4	5.9	6.3	5.5	5.3
	(2.2)	(2.2)	(2)	(1.9)	(1.9)	(2.2)	(2.5)	(2.6)	(2.6)	(2.8)
Time	150.7	138.8	121.5	128.3	146.7	135.7	151.8	151.5	137.2	138.2
	(58.5)	(61.9)	(51.4)	(63.8)	(62.6)	(70.6)	(73.6)	(83.6)	(86.1)	(85.8)

The values are expressed as mean (standard deviations). *M* males, *F* females, *GHFT* Gottschaldt's Hidden Figure Test, *HF* Hidden Figure Identification, *MR* mental rotations

The ANOVA on MR time score did not show significant main effects or interactions (all $p > .05$).

Mean scores on AQ, EQ and SQ separately for both the five degree subjects and sex are reported in Table 3.

For the AQ, results of the MANOVA did not show a significant effect of the degree subject ($p > .05$), whereas we found a significant main effect of sex (Pillai's trace = .066; F(5337) = 4.77; $p = .0001$, $\eta_p^2 = .066$). The degree by sex interaction was not significant ($p > .05$). For sex, there were significant univariate effects on: AQ attention switching (F(1341) = 7.24, $p = .007$, $\eta_p^2 = .021$), AQ imagination (F(1341) = 9.04, $p = .003$, $\eta_p^2 = .026$) and AQ attention to detail (F(1341) = 4.57, $p = .033$, $\eta_p^2 = .013$), with higher scores of males than females on AQ attention switching and on AQ imagination, whereas females scored higher than males on AQ attention to detail.

For the EQ, the MANOVA did not show significant main effects of degree subject and sex ($p > .05$). There was a significant degree subject by sex interaction (Pillai's trace = .109; F(16,1364) = 2.38; $p = .002$, $\eta_p^2 = .027$), with significant univariate effects for EQ emotional reactivity (F(1341) = 2.54, $p = .029$, $\eta_p^2 = .029$); however, no difference was significant at the Bonferroni-corrected $p = .00125$ (.05/40).

For the SQ, the ANOVA showed a significant main effect of degree subject (F(4341) = 6.56, $p = .0001$, $\eta_p^2 = .071.071$); Bonferroni-corrected post hoc comparisons ($p = .0025$) showed that biological scientists scored significantly lower than engineering-design students ($p = .0001$), while no other comparisons were significant (all $p > .0025$). The main effect of sex and the degree subject by sex interaction were not significant ($p > .05$).

Modelling relations between autistic traits, degree subject and visuospatial performance

Results from path analysis showed a sufficient fit for the basic model, ML$\chi^2(6) = 20.94$; $p = .002$; ML$\chi^2/df = 3.48$; RMSEA = .084 [90% CI .047; .125]; CFI = .957. Therefore, the not statistically significant paths were pruned and the fit of the pruned model was tested showing a good fit, ML$\chi^2(21) = 43.70$, $p = .003$, ML$\chi^2/df = 1.51$, RMSEA = .055 [90% CI .032; .078], CFI = .935, and that the more parsimonious model did not cause a significant loss of fit, ML$\chi^2_{\text{diff}}(15) = 14.17$, $p =$ ns. This latter model was considered the best fitting one (Fig. 2). When controlling for the SQ total score, the AQ attention to detail had no significant association either with the academic degree or the visuospatial performance. When controlling for the AQ attention to detail, the SQ total score was specifically related to the academic degree. The higher was the SQ score ($\gamma = .38$, $p < .001$), the higher was the likelihood of being in G2 (engineering-design) compared to G1 (physical sciences), whereas the lower was the likelihood ($\gamma = -.34$, $p < .001$) of being in G4 (biological sciences) compared to G1. As regards visuospatial abilities, data showed that when controlling for traits, academic degree was specifically related to visuospatial performance. In particular, G2 showed a better performance then G1 on GHFT ($\beta = .62$, $p < .001$) and MR ($\beta = .30$, $p < .001$); G3 showed a better performance then G1

Table 3 AQ, EQ and SQ scores, separately for sex and degree subject

	Physical sciences		Engineering-design		Fact-based humanities		Biological sciences		Systems-based social sciences	
	M	F	M	F	M	F	M	F	M	F
AQ total score	17.9	17.1	18.9	19.3	17.9	17.5	17.3	16.5	19.5	18.3
	(5.2)	(5.9)	(3.7)	(5.1)	(6)	(6.9)	(5.5)	(5.7)	(6.4)	(4.3)
AQ social skill	2.2	2	1.7	2.4	2.8	1.9	1.8	2.2	2.5	2.1
	(2)	(2)	(1.2)	(2.2)	(1.9)	(2.4)	(1.9)	(2.1)	(2.1)	(1.2)
AQ attention switching	5	4.4	5	4.8	4.8	4.2	4.7	4.3	5	4.2
	(1.7)	(1.9)	(1.5)	(1.7)	(1.8)	(2)	(1.9)	(1.9)	(1.5)	(1.4)
AQ attention to detail	5.4	5.4	5.7	6.4	5.4	6.5	5.1	5.3	5.8	6.5
	(2.3)	(2.5)	(2)	(2.2)	(3)	(2.4)	(1.9)	(2.4)	(2.3)	(2.2)
AQ communication	2.3	2.5	2.6	2.9	2.2	2.3	2.6	2.2	2.6	2.8
	(1.7)	(1.9)	(1.6)	(1.8)	(1.4)	(1.9)	(1.6)	(2)	(1.9)	(1.4)
AQ imagination	3	2.9	3.9	2.9	2.8	2.7	3.1	2.5	3.6	2.6
	(1.6)	(1.5)	(1.7)	(1.7)	(1.8)	(1.8)	(1.7)	(1.6)	(2)	(1.6)
EQ total score	43	40.8	38.8	42.4	42	41.1	43.3	46.1	42	41.9
	(10.6)	(10.4)	(8.7)	(9.3)	(11.9)	(10.9)	(10.5)	(11.1)	(9.8)	(6.5)
EQ social skills	6.2	7.2	6.1	6.3	6.6	6.7	6.4	7.2	7	6
	(2.5)	(2.5)	(2.5)	(2.1)	(2.7)	(2.2)	(2.7)	(2.7)	(2.6)	(1.9)
EQ cognitive empathy	17.5	16.3	15.3	16.3	15.1	16.5	17.1	18.1	17.0	16.1
	(5.6)	(5.7)	(4.5)	(3.9)	(5.8)	(6)	(5)	(6)	(5.1)	(5)
EQ emotional reactivity	13.5	12.3	12.3	15.0	14.7	13.2	14.3	14.3	12.5	14.8
	(4.8)	(4.5)	(3.9)	(4.9)	(5)	(5.2)	(4.7)	(4.4)	(4.9)	(3.4)
SQ total score	33.5	35.2	38.6	40.2	32.1	37.0	28.0	30.9	35.6	29.0
	(10.7)	(12.4)	(9.4)	(10.9)	(13.6)	(14.3)	(10.2)	(11.4)	(11.9)	(11.5)

The values are expressed as mean (standard deviations). *M* males, *F* females, *AQ* Autism Quotient, *EQ* Empathy Quotient, SQ Systemizing Quotient

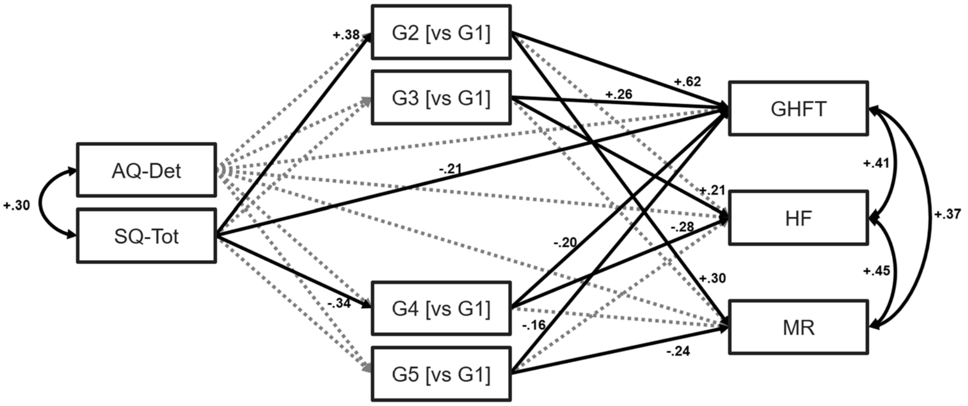


Fig. 2 Path analysis of the model predicting visuospatial performance. *Note* Each arrow was associated with a standardized coefficient; dashed lines indicate non-significant paths ($p > .05$); solid lines indicate significant paths ($p < .05$). *AQ-Det* AQ attention to detail, *SQ-Tot* SQ total score, G1: physical sciences; G2: engineering-design; G3: fact-based humanities; G4: biological sciences; and G5: systems-based social sciences; *GHFT* Gottschaldt's Hidden Figure Test accuracy, *HF* Hidden Figure test accuracy, *MR* mental rotations accuracy

on GHFT ($\beta = .26$, $p = .008$) and HF ($\beta = .21$, $p = .006$); G4 showed a less accurate performance then G1 on both GHFT ($\beta = -.19$, $p = .007$) and HF ($\beta = -.28$, $p < .001$); and G5 showed a less accurate performance then G1 on both GHFT ($\beta = -.16$, $p = .021$) and MR ($\beta = -.24$, $p = .002$).

Finally, as regards the investigation of direct and the indirect effects of autistic traits on visuospatial abilities, data showed that when controlling for SQ total score and the academic degree subject, AQ attention to detail had no specific effect on visuospatial abilities, either direct or indirect. When controlling for the AQ attention to detail and the academic degree subject, data showed that the academic degree subject mediated the effect of SQ total score on visuospatial performance. Indeed, data showed that SQ total score had a significant indirect effect on GHFT mediated by G2 (standardized indirect effect = .235; BC 95% CI [.126; .395]) and G4 (standardized indirect effect = .067; BC 95% CI [.019; .137]); an indirect effect on HF mediated by G4 (standardized indirect effect = .096; BC 95% CI [.044; .169]); and an indirect effect on MR mediated by G2 (standardized indirect effect = .112; BC 95% CI [.047; .191]).

Moreover, results showed that SQ total score had a significant direct effect on GHFT (standardized direct effect = − .208; BC 95% CI [− .381; − .067]). This latter result seems to indicate the existence of a partial mediation effect. However, the analysis of the effects showed that the total effect of SQ total score on GHFT was not significant (standardized total effect = .094; BC 95% CI [− .002; .194]), whereas the total indirect effect was significant (standardized total indirect effect = .302; BC 95% CI [.171; .482]). This pattern of data seems to point to the existence of a "competitive mediation" (Zhao et al. 2010; p. 200), suggesting the existence of omitted mediators possibly explaining the results.

Discussion

Results showed that engineering-design students were the most accurate in disembedding and mentally rotating figures, followed by students of physical sciences and fact-based humanities; biological and systems-based social scientists were the least accurate. Engineering-design students also showed higher systemizing scores with respect to the other four academic degree subjects, with students of biological sciences showing lower systemizing scores. Sex differences were never observed in none of the three visuospatial tasks, whereas they were found on AQ attention switching and imagination, with males scoring higher than females, and on AQ attention to detail, with females scoring higher than males. Results from the self-report measures generally fit data showing higher autistic traits in males than in females (Baron-Cohen et al. 2003), while results from the visuospatial tests are consistent with growing literature reporting no sex differences on visuospatial tasks. Indeed, although here we used a two-dimensional mental rotations task yielding to smaller sex differences than three-dimensional mental rotations (Voyer et al. 1995), recent findings suggest that since both sexes are nowadays equally engaged in technology, males and females can experience comparable training with visuospatial tasks and gain comparable performance on tests such as mental rotations, thus implying that sex differences in visuospatial abilities are also related to social experience (e.g. Groen et al. 2018; Rodán et al. 2016). For instance, recently Groen et al. (2018) found that male and female university students from different academic majors did not differ on visuospatial tasks assessing mental rotations, mental construction and figure disembedding. The authors suggested that since their sample mainly included young persons raised in an era of digital technology, this could have favoured an analogous visuospatial training between sexes, likely reducing the typical sex differences found in the previous literature. This interpretation is in line with data from studies on the effects of visuospatial training demonstrating that visuospatial skills are malleable (Uttal et al. 2013).

The stronger visuospatial abilities and systemizing tendencies in engineering-design students than in physical scientists and fact-based humanities students, and in biological and social scientists were a novel finding. Indeed, although we confirmed that students from different majors display distinctive visuospatial abilities and systemizing (Baron-Cohen et al. 2001; Billington et al. 2007; Groen et al. 2018; Kidron et al. 2018; Wheelwright et al. 2006), the novelty of our results lies in that we did not confirm the dichotomy between physical sciences and social sciences/humanities, since we rather found a more nuanced picture with large similarities, on the one hand, between engineering-design, physical sciences and fact-based humanities and, on the other, between biological and system-based social sciences. The inconsistencies between results could be related to the different types of majors that were included in the academic subject categories across studies (see Appendix B for a complete list of majors included in Baron-Cohen et al. 2001; Billington et al. 2007; Focquaert et al. 2007; Groen et al. 2018; Kidron et al. 2018; Wheelwright et al. 2006). Indeed, it is possible to suggest that by including in each academic subject majors differing in the degree of systemizing, previous studies could have cancelled out differences that instead were revealed here by recruiting a limited number of homogeneous and high systemizing majors. For instance, Focquaert et al. (2007) compared students from sciences (mathematics, engineering, physics and chemistry) with students from humanities (French and English) and confirmed that individuals in the sciences were more systemizing-driven, whereas individuals in humanities were more empathizing-driven. However, when the authors looked at possible differences between majors in sciences, they found that there were significant differences across majors, with the systemizing pattern being especially pronounced in physicists and engineers than in mathematicians and chemists. Hence, here we were able to improve upon previous studies by looking at finer classification of the degree subjects.

Results of the path analysis confirmed that the choice of specific academic subjects was linked to own individual traits as systemizing or attention to detail, but with systemizing showing an effect that was observed over and above the others. In particular, higher scores on SQ were found in students of engineering-design compared to students of physical sciences, whereas lower SQ scores were observed in students of biological sciences with respect to students of physical sciences. These results are consistent with literature reporting strong systemizing in students of engineering and physical sciences (Baron-Cohen et al. 2001; Billington et al. 2007; Focquaert et al. 2007; Groen et al. 2018; Kidron et al. 2018; Wheelwright et al. 2006). However, future studies measuring SQ and other variables before the person has embarked on the degree are needed to test whether own systemizing tendency can differentiate the entry into some specific majors, as engineering-design vs. physical sciences vs. biological sciences.

Importantly, we also demonstrated that SQ exerted an indirect effect on visuospatial performance through the influence of the academic degree. More precisely, academic degree subject mediated the effect of systemizing on figures disembedding and mental rotations, with a specific mediation of engineering-design on one disembedding figure task, i.e. GHFT, and on mental rotations (MR), and of biological sciences on both the two disembedding figure tasks (GHFT and HF). On the contrary, autistic traits assessed by AQ never affected visuospatial performance. This fits the previous literature showing that SQ but not AQ is correlated with spatial thinking and interest in mechanical reasoning, mathematics and engineering (Morsanyi et al. 2012), suggesting that although engineers and mathematicians can show increased autistic traits, this might not be related to the "autistic personality" in general but rather to particular aspects of the "autistic cognitive style" as systemizing.

Thus, we can support the view that figure disembedding and mental rotations are strongly related to systemizing. However, we can also suggest that the kind of task used to measure these visuospatial abilities may allow to highlight differences between persons sharing comparable high levels of systemizing tendencies. In particular, GHFT is a classical disembedding figure test requiring participants to provide a motor response to trace the simple embedded figure within a complex, global pattern (Gottschaldt 1926). At variance, HF requires a perceptual matching between different alternatives to find the embedded figure (La Femina et al. 2009). The advantage of engineering-design students with respect to physical scientists might imply that although the two majors include students sharing a comparable degree of perceptual disembedding abilities, as shown by performance on HF, the emphasis of engineering-design on disciplines as technical drawing might have favoured engineering-design students in the figure disembedding test requiring a motor response. The same might be true for mental rotations, since also MR performance was influenced by academic degree with the best score provided by engineering-design students. However, it is worth underlining here that our research design did not allow us to establish whether people with higher visuospatial abilities choose a major as engineering-design rather than biological sciences or whether practising with visuospatial material could have enhanced the ability to perform complex tasks, as the GHFT and mental rotations, while leaving unaffected more basic visuospatial abilities only requiring a perceptual judgment, as in the HF. This limitation could be overcome by longitudinal or randomized studies allowing to compare these alternatives.

Persons with high autistic traits show motor coordination difficulties, and accordingly, dyspraxia is commonly observed in ASC (Cassidy et al. 2016; Gowen and Hamilton 2013). On this basis, one could assume slower responses of these persons in tasks requiring complex motor responses, as the GHFT used in the present study. On the contrary, one might have expected to find faster responses on visuospatial tasks with a computer presentation and a simple button press. Thus, measuring the time to complete motorically complex paper-and-pencil tests could not be the most suitable way to assess visuospatial performance in the present sample. Although this is a post hoc interpretation, by bearing in mind this methodological caveat, the present data might contribute to clarify inconsistences reported in the literature on figure disembedding and mental rotations in persons with ASC. Such discrepancies are likely due to the methodological approaches used in the analysis of participants' performance (Muth et al. 2014). In particular, when considering overall mental rotations performance, ASC participants outperform typical controls, whereas a closer look at task aspects demonstrates that ASC individuals do not outperform neurotypicals on rotational aspects of the task but rather on the non-rotational ones (Falter et al. 2008). Here, we could speculate on the possible involvement of a further factor, that is, practising with spatial-related abilities. Actually, following evidence reviewed above on the malleability of visuospatial abilities (Uttal et al. 2013), and consistent with the present results, one might suggest that leaving uncontrolled individuals experiencing with visuospatial activities could influence the possibility to detect differences between ASC and neurotypical individuals on mental rotations and complex figure disembedding tasks. Thus, future studies on visuospatial performance in ASC should take into account individuals' degree of experience with spatial-related activities. Indeed, since visuospatial activities are those preferred by persons with ASC and those to which persons with ASC dedicate a lot (Baron-Cohen 2002; Baron-Cohen et al. 2009), it is possible that individual differences in the time spent with these activities might mould more hardwired, biological differences in visuospatial performance.

Among the study limitations was the lack of self-report measures assessing aspects of individuals' cognitive style potentially influencing the relationship between systemizing, academic major and visuospatial performance. Indeed, results of the path analysis suggested the existence of omitted mediators possibly elucidating the effect of systemizing on figure disembedding. Morsanyi et al. (2012) demonstrated that the effect of systemizing on mathematical performance is mediated by the spatial thinking style that is the ease with which an individual relies upon spatial mental imagery to solve a problem. Following these results, we can hypothesize that the spatial thinking style could represent a variable possibly clarifying the relationship between systemizing and visuospatial abilities. Finally, we did not recruit students from non-systemizing degree disciplines (e.g. literature, drama, counselling psychology, social work). In particular, we excluded the non-systems-based social sciences and the non-fact-based humanities. Our choice was because the main focus of the present study was to investigate shady differences within systemizing-based degree subjects, rather than overt differences between systemizing- and non-systemizing-based degree subjects. However, even with systemizing-based disciplines, we demonstrate that systemizing exerts an indirect effect on figure disembedding and mental rotations through the influence of the academic degree. Future studies could also include non-systemizing disciplines to further elucidate this relationship.

Notwithstanding the above limitations, the present findings contribute to the debate on the role of visuospatial competences in science, technology, engineering and mathematics (STEM) disciplines. A large number of studies demonstrated a clear relation between visuospatial abilities and both the choice and the progress in sciences (Uttal et al. 2013; Wai et al. 2009). Here, we suggest that progress in science could be further guided by adding to the scientific courses a specific visuospatial training. Moreover, it could be useful to train visuospatial abilities even in students reading disciplines as medicine (biological sciences) who show low systemizing abilities and weak visuospatial abilities, consistent with a literature demonstrating that visuospatial competences, especially the most complex ones, are crucial for students of different branches of medicine, as surgeons or radiologists (Birchall 2015). In other words, one could speculate that students reading majors which could benefit from good visuospatial skills but who actually show low systemizing tendencies and few visuospatial prerequisites, might undergo training courses focused on practising with complex visuospatial problems, such as figure disembedding and mental rotations.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights statement The present research involves human participants.

Informed consent The research was conducted after participants provided written informed consent and in accordance with the ethical standards of the Helsinki Declaration.

Appendix A

See Table 4.

Table 4 Summary of intercorrelations between variables considered in the path model

Variables[a]	1	2	3	4	5	6	7	8
1. AQ-Det								
2. SQ-Tot	.300***							
3. G2 vs G1	.084	.235***						
4. G3 vs G1	.032	−.038	−.194***					
5. G4 vs G1	−.102	−.202***	−.270***	−.265***				
6. G5 vs G1	.088	−.031	−.177***	−.173***	−.241***			
7. GHFT	−.012	.108*	.222***	.137*	−.174***	−.121*		
8. HF	.019	.110*	.058	.130*	−.222***	−.018	.400***	
9. MR	−.010	.163**	.154**	.072	−.087	−.179***	.459***	.395***

[a] *AQ-Det* AQ attention to detail, *SQ-Tot* SQ total score, G1: physical sciences; G2: engineering-design; G3: fact-based humanities; G4: biological sciences; G5: systems-based social sciences; *GHFT* Gottschaldt's Hidden Figure Test accuracy, *HF* Hidden Figure Test accuracy, *MR* mental rotations accuracy. $^{*}p < .05$; $^{**}p < .01$; $^{***}p < .001$

Appendix B

See Table 5.

Table 5 List of majors included in the academic subject categories according to previous literature

	Physical sciences	Biological sciences	Social sciences	Humanities
Baron-Cohen et al. (2001)[a]	Physics, physical natural sciences, chemistry, geology, communications, chemical engineering, mineral science, material science and geophysics	Experimental psychology, neurophysiology, biological natural sciences, biology, bioanthropology, neuroscience and molecular ecology	Geography, economics, social and political sciences, archaeology and anthropology, land economy or management	Classics, languages, law, architecture, philosophy, English, theology, history or music
Wheelwright et al. (2006)	Mathematics, physics, physical natural sciences, chemistry, computer science, geology, communications, engineering, manufacturing engineering, chemical engineering, mineral science, material science, astrophysics, astronomy and geophysics	Experimental psychology, neurophysiology, biochemistry, molecular biology, biological anthropology, biology, neuroscience, medicine, veterinary medicine, anatomy, genetics, pharmacology, physiology, plant sciences and zoology	Geography, economics, commerce, social and political sciences, archaeology, anthropology, land economy, international relations and management	Classics, languages, drama, education, law, architecture, philosophy, oriental studies, English, linguistics, theology, history, history and philosophy of science, history of art and music
Billington et al. (2007)	The same majors as in Wheelwright et al. (2006)			Classics, languages, drama, education, law, architecture, Anglo-Saxon, Norse and Celtic Studies, philosophy, oriental studies, English, linguistics, theology, history, history and philosophy of science, history of art and music
§Focquaert et al. (2007)	Mathematics, engineering, physics and chemistry			French and English
Groen et al. (2018)[c]	Applied mathematics, biology, chemical engineering, chemistry, computing science, life science and technology, mathematics, physics, pharmacy, industrial engineering and management		Theory of education, educational sciences, psychology or sociology	
Kidron et al. (2018)[b]	Mathematics, physics, engineering, computer science, biology, actuarial science, finance, chemistry and accounting			Psychology, education, art, music, business, speech therapy and political science

This Appendix does not include the academic degree classification by Manson and Winterbottom (2012), as the authors compared two categories, i.e. sciences and arts, comprising a very large range of majors (about 30 items in sciences and 40 items in arts) spanning across the four categories included in the present Appendix

[a] Baron-Cohen et al. (2001) combined together physical and biological sciences in a category labelled sciences, also including mathematics, computer science, engineering, medicine (and veterinary science) and nonspecific science (included those subjects who simply listed their degree as natural sciences, which could have been any of the sciences)

[b] Focquaert et al. (2007) and Kidron et al. (2018) named physical sciences as science

[c] Groen et al. (2018): all students from majors in the social sciences category were recruited from the Faculty of Behavioural and Social Sciences at the University of Groningen emphasizing statistical methodology and biology

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